N88-25713

MSAT-X PHASED ARRAY ANTENNA ADAPTIONS TO AIRBORNE APPLICATIONS

C. SPARKS, H.H. CHUNG, and S.Y. PENG, Teledyne Ryan Electronics, San Diego, California

TELEDYNE RYAN ELECTRONICS
8650 Balboa Avenue
San Diego, California 92123

ABSTRACT

The MSAT-X Phased Array Antenna is being modified to meet future airline requirements. The proposed antenna system consists of two high gain antennas mounted on each side of a fuselage, and a low gain antenna mounted on the top of the fuselage. Each of the two high gain antennas is an electronically-steered phased array based on the design of the MSAT-X antenna, as described in a separate paper. The major difference is in the beam forming network which is connected to the array elements via coaxial cables. This approach allows the array elements fuselage conformal (0.37 inches thickness). In addition, the circuit board containing the diode phase shifters will be installed inside the aircraft to increase the MTBF and reliability, to ease of maintenance, and to ultimately reduce the cost. It is essential that the proposed antenna system be able to provide adequate communication link over the required space coverage which is 360 degrees in azimuth and from 20 degrees below the horizon to the zenith in elevation. Alternative design concepts are suggested to maximize space coverage and redundancy capabilities. Both open loop tracking system and close loop backup capabilities are discussed. Typical antenna system performance data measured are also included.

INTRODUCTION

To meet the challenging aviation satellite communication requirements, Teledyne Ryan Electronics (TRE) developed an antenna subsystem for this application, based on the MSAT-X phased array design. The major features of the developed phased array are its low profile (0.37 inch in thickness), wide space coverage (using crossed-slot element), good satellite isolation (>20 dB), built in redundancy (center element used as a low gain antenna for backup during phase shifter failure), and good pointing performance. The design concept is aimed for low cost, low drag, high reliability, ease of installation and maintenance, low technical risk, and maximum redundancy and space coverage.

SYSTEM CONFIGURATION

The original antenna subsystem configuration proposed consists of two identical high gain antennas, one low gain antenna as backup, 3 diplexers, 3 low noise amplifiers (LNA), and the associated electronics circuits and power supply. The locations proposed are the two sides of fuselage for high gain antennas and the top of fuselage for the low gain antenna as shown in Figure 1. The proposed low gain antenna is a printed crossed-slot which has low profile (0.37 inch) and wide space coverage as shown in Figure 2.

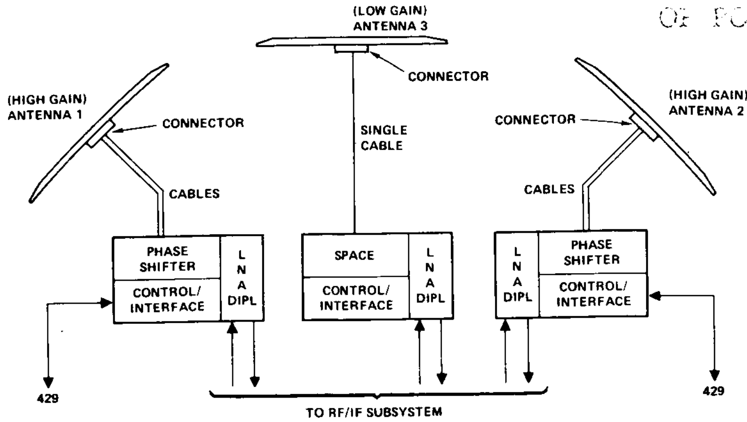


Fig. 1. Original antenna subsystem

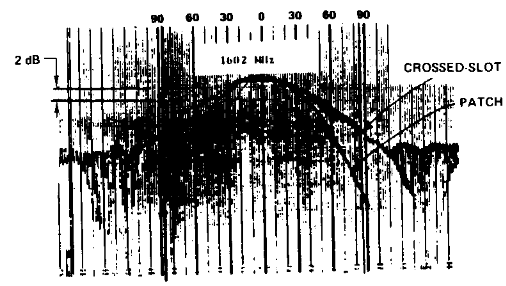


Fig. 2. Crossed-slot element radiation pattern

Note that the gain drop at 7 degrees above horizon from the peak of element pattern is about 8.5 dB. The measured peak gain is 5.5 dBic. Therefore, the gain at the 7 degrees above the horizon is -3.0 dBic which does not meet the specified gain of 0 dBic. For a patch antenna, however, the gain drop is 19 dB from the peak as shown in Figure 2. Therefore, the crossed-slot element is the best low profile element for the satellite communication. To further illustrate this fact, three conical cut pattern data for a crossed-slot element mounted on top of a Remote Pilot Vehicle (RPV) is shown in Figure 3. Note that the gain at the 0 degree azimuth angle is -3.8, -3.2, and -2.0 dBic respectively, at elevation angles of 0, 5, and 10 degrees

Since the low gain antenna cannot meet the gain requirement of 0 dBic at +7 degrees above horizon, and the redundancy is desired by airlines, an alternative system concept which consists of 3 identical high gain antennas are proposed as shown in Figure 4. The major difference from the original approach is that the new approach replaces the low gain antenna by a high gain antenna. The key advantages by doing so are to provide redundancy space coverage, to maximize the commonalty of components, and to minimize the "key hole" areas. If a single top-mounted high gain antenna is desired (rather than the conformal array approach), a cap antenna using crossed-slot elements can be designed and developed to meet the need of this challenging application.

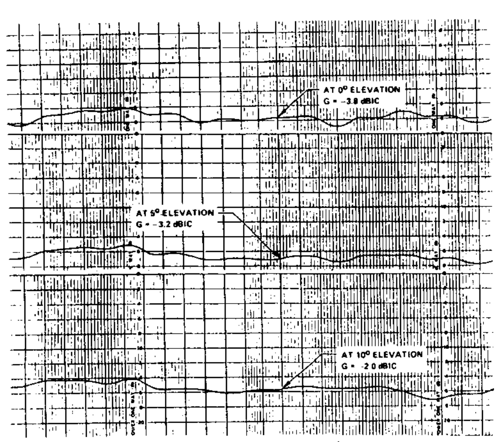


Fig. 3. Measured conical cuts of a TRE crossed-slot element at elevation angles of 0°, +5°, and +10°

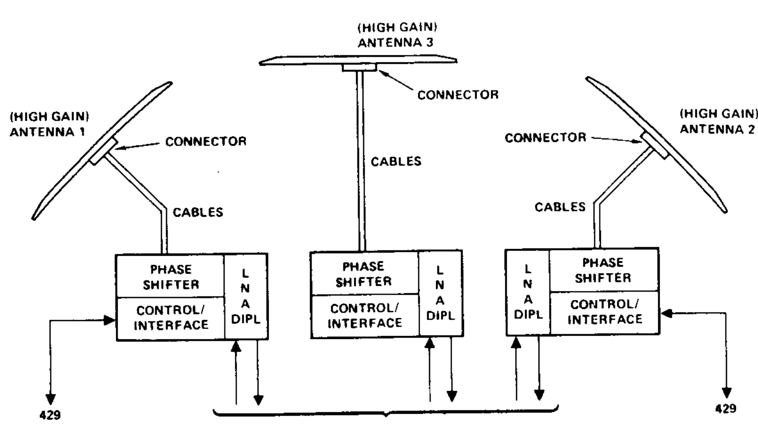


Fig. 4. Alternative antenna subsystem configuration

INSTALLATION CONCEPT

To simplify aircraft installation, the TRE's antenna subsystem has only 3 physical groups per high gain antenna: the antenna, a RF cable, and an electronic box. Figure 5 shows the proposed antenna installation concept. Note that the high gain antenna is mounted outside of the fuselage with the foot print according to the ARINC 741 characteristics which is illustrated in Figure 6. The electronics box is mounted inside the fuselage close to the high gain antenna. Figure 7 shows the proposed electronics box dimension. An 18 inch long RF cable is used for the connection between the antenna and the electronics box. One end plugs into the antenna with a special connector consisting of 19 0.141 semi-rigid cables. The other end of the RF cable plugs into a beam forming network contained inside the electronics box. Figure 8 shows a design of the 19-cable RF connector. In addition, the box also contains a diplexer, LNA, and DC power supply.

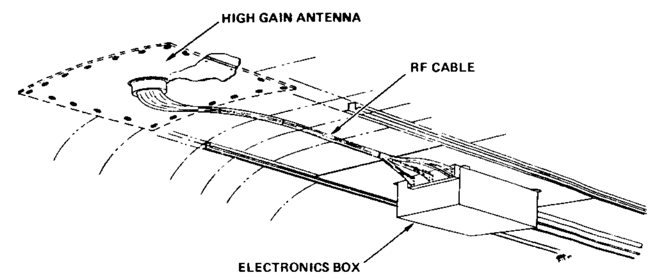


Fig. 5. Antenna installation concept

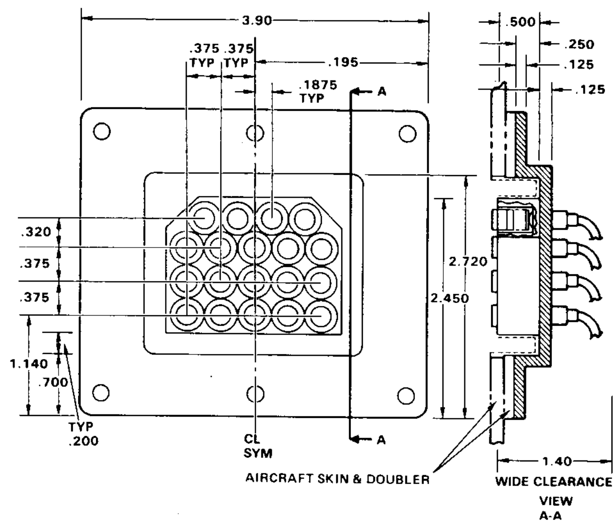


Fig. 8. A 19-cable rf connector design

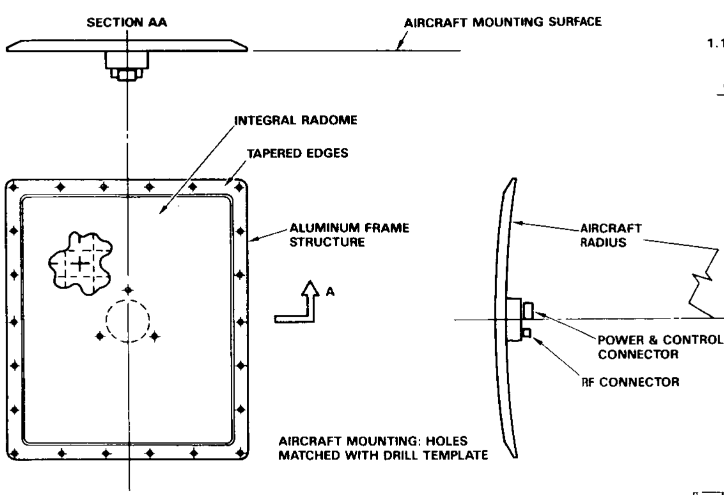
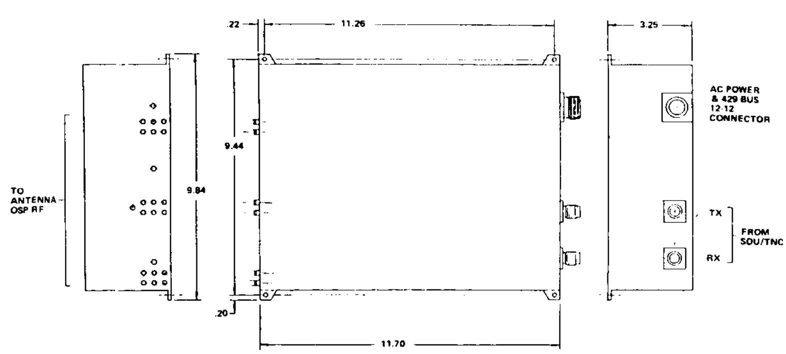


Fig. 6. High gain antenna subsystem



THE BOX CONTAINS:

- LNA DIPLEXER
- BEAM FORMING NETWORK (BFN)
- BEAM STEERING UNIT (BSU)
- DC POWER SUPPLY

Fig. 7. Electronics box dimensions

ANTENNA SUBSYSTEM CHARACTERISTICS

As mentioned previously, the antenna subsystem has two (or three for the alternative approach) high gain antennas. Each antenna has 19 crossed-slot elements with the center one used as a reference which does not have a phase shifter. This feature provides the redundancy capability for the low gain antenna as a backup during the phase shifter failure. Table 1 summarizes the antenna subsystem characteristics for two side-mounted and one top-mounted high gain antennas. It should be emphasized that the low profile characteristics does offer the low drag property. Tables 2 and 3 show results of drag coefficient calculated by the Boeing Company for 747-400 and 767 aircraft, respectively, as a function of antenna mounting locations. Two different thickness of conformal arrays were used, such as 0.37 and 0.60 inch. Note that the 0.37 inch thick antenna has lower drag coefficient and does save money significantly in fuel burn yearly.

The array gain as a function of scan angle is given in Figure 9. Note that the gain at the 60 degrees scan angle is 12 dBic which meets the specified value. The gain drops off very fast for scan angles greater than 60 degrees. At scan angle of 90 degrees, the calculated array gain is 3 dBic. Therefore, the top-mounted high gain antenna not only provides the redundancy for the two side-mounted conformal array, but also provides better than 0 dBic (~3 dBic) antenna gain at the horizon which is required for the backup low gain antenna. In addition, the "key hole" areas are minimized, by the judicious choice of array locations. Figure 10 shows the space coverage of the two side-mounted TRE's conformal arrays which is better than other conformal arrays.

The pointing system adapted for the airborne application is based on the MSAT-X design with some modifications. The MSAT-X design uses hybrid approach which includes both the open-loop and closed-loop operation, to optimize the antenna steering toward to satellite. A rate sensor was used during the open-loop operation for the MSAT-X program which will not be adapted here. Instead, the navigation data will be provided as the input to steering the beam pointing directions. For the closed-loop operation, a sequential lobing technique was used to search track satellite locations.

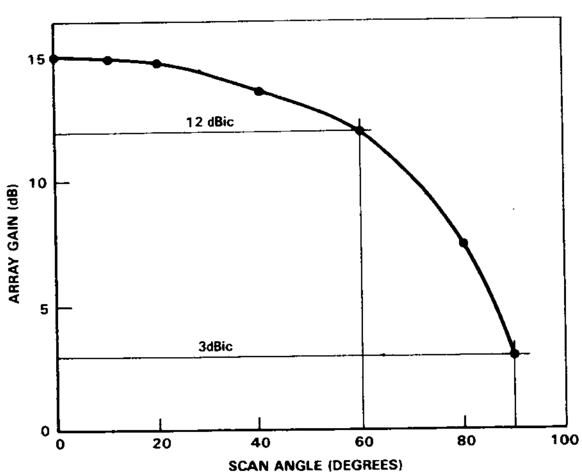


Fig. 9. Array gain as a function of scan angle away from the array normal

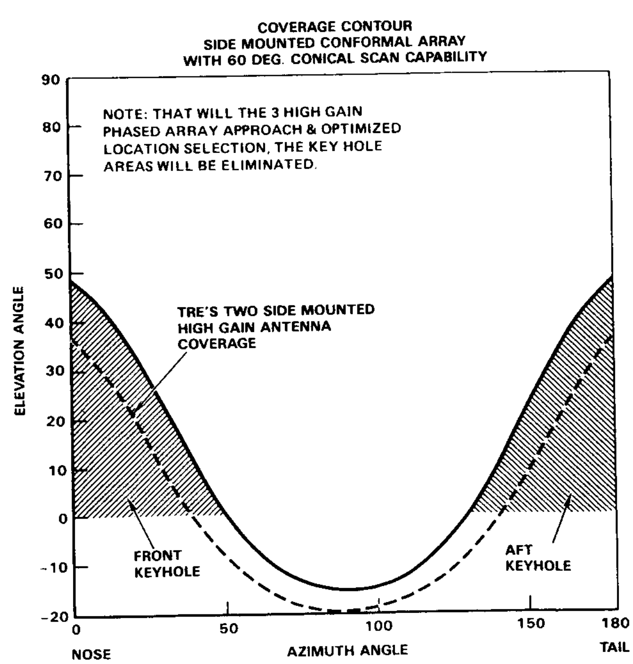


Fig. 10. Space coverage of two side-mounted conformal arrays

Table 1. Antenna subsystems characteristics	
Frequency of Operation	
Transmit	1625.5 to 1660.5 MHz
Receive	1530.0 to 1559.0 MHz
Polarization	Right hand circular polarization (RHCP)
Gain (high hain antenna)	
Broadside	15 dBic
At $\pm$60 scan angle	12 dBic
Space coverage	
Elevation	-20° to +90° (for two side-mounted arrays) +30° to +90° (for one top-mounted array)
Sidelobe discrimination	13 dB at 45° separation
Satellite Isolation	>20 dB
Low profile	$\geq$0.5 inch in thickness above fuselage

Table 2. Satcom antenna drag estimate summary for 747-400 aircrafts (side-mounted conformal array antennas)

Location (BST)	Drag*		CBRGW*		FCL*	
	0.37"	0.60"	0.37"	0.60"	0.37"	0.60"
450	0.025	0.045	65	115	150	270
700	0.020	0.030	50	75	120	180
825	0.025	0.030	65	75	150	180
1150	0.025	0.040	65	150	150	240
1350	0.020	0.040	50	100	120	240
1550	0.020	0.030	50	75	120	180
1750	0.015	0.025	40	65	90	150
1800	0.015	0.025	40	65	90	150
1950	0.015	0.025	40	65	90	150

Table 3. Satcom antenna drag estimate summary for 767 aircrafts (side-mounted conformal array antennas)

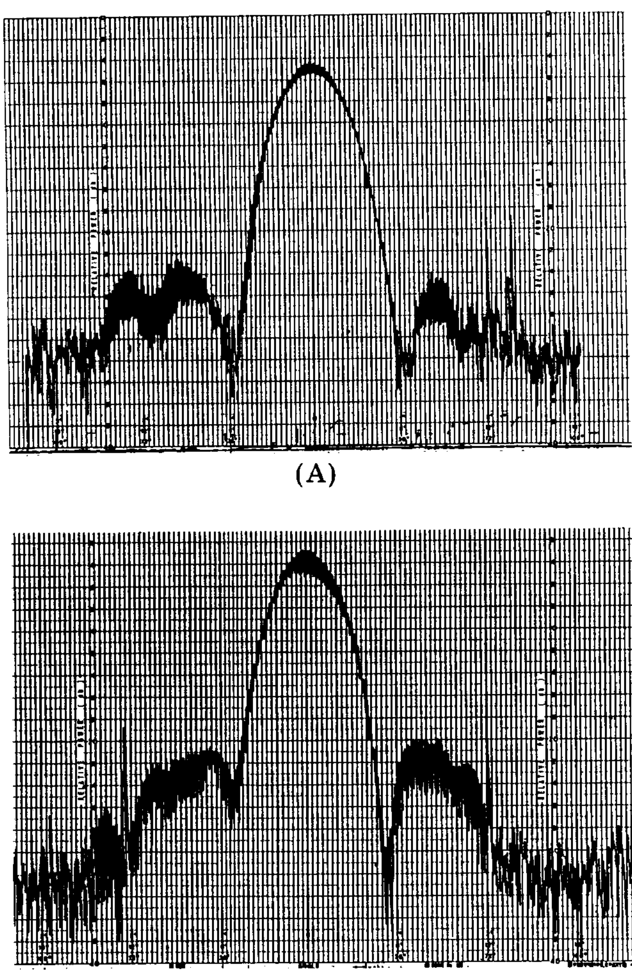
Location (BST)	Drag*		FCL Burn* (GAC/Ap/Yr)	
	0.37"	0.60"	0.37"	0.60"
450	0.004	0.024	190	1020
650	0.004	0.019	150	800
730	0.003	0.018	140	760
930	0.005	0.026	200	1100
1130	0.003	0.017	130	700
1300	0.003	0.015	120	630

* CBRGW = Constant brake release gross weight mission.
* FCL = Fuel capacity limited mission.
* DRAG = In percent of total airplane drag at cruise. All fuel burn penalties based upon 2000 N.U. mission. 795 flights/yr. Numbers were calculated for the 767-200. Levels for the 767-300 would be similar.

MEASURED PERFORMANCE

The measured TRE's antenna pattern performance is given in Figure 11 and 12. Figure 11 shows the measured broadside array pattern on top of a 40" x 50" groundplane. The achieved axial ratio and sidelobe level are very good for frequencies at both 1545 and 1660 Mhz. The patterns were taken using spinning linear source. Figure 12 shows the patterns scanned to 60 degrees away from the array normal. Again, the patterns and axial ratio are well behaved. The measured array gain at the 60 degrees scan angle is averaged at 10.7 dBic and 10.3 dBic, respectively, for frequencies of 1545 and 1660 MHz. The deficiency in array gain is being resolved under the present contract with JPL on the MSAT-X Mechanically Steered Array Program.

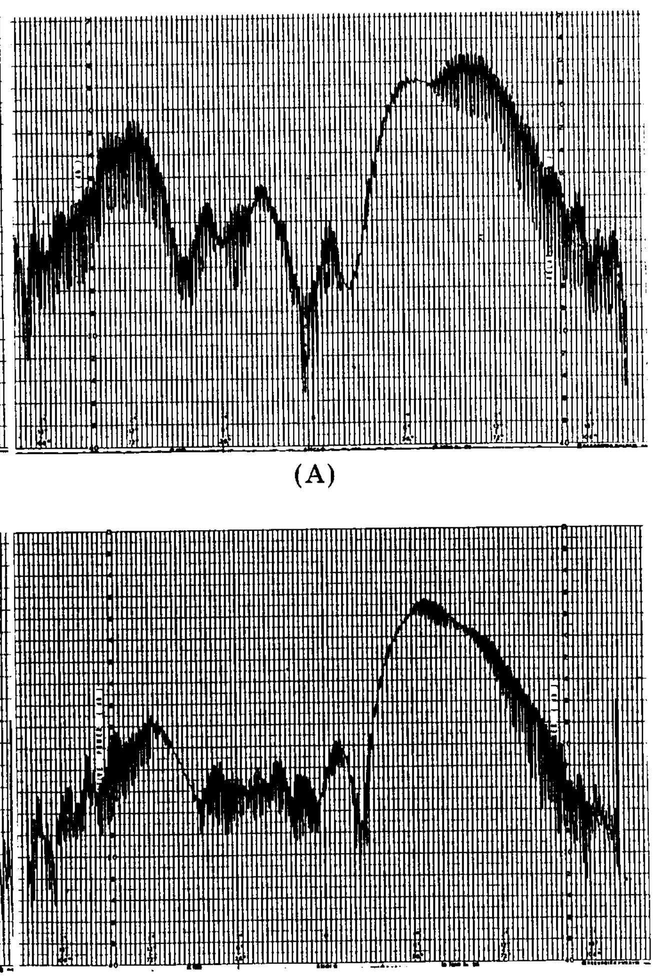
The measured pointing system performance for the MSAT-X program was very satisfactory, even under the current array gain deficiency condition. The system adapted is a hybrid mode pointing system operated under open loop and close loop conditions. The close loop operation is using a sequential lobing technique to search and track satellite signals. The open loop tracking is suing an inertial sensor which was a rate sensor during tests. This hybrid system performed well during the acceptance test, under both fading and high power conditions. The measured intersatellite isolation was better than 20 dB as specified. This pointing system can easily be modified for the aviation satellite communication.



(A)

(B)

Fig. 11. Measured broadside array patterns for frequencies of 1545 and 1660 GHz



(A)

(B)

Fig. 12. Measured array patterns at scan angle of 60 degrees away from array normal for frequencies of 1545 and 1660 GHz